National Aeronautics and Space Administration

NASA

Advances in High Energy Solid-State Pulsed 2-micron Lidar Development for Ground and Airborne Wind, Water Vapor and CO_2 Measurements

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April 12-17 2015, EGU, Vienna, Austria

Engineering Directorate

Concept-to-Flight

www.nasa.gov

http://engineering.larc.nasa.gov/

Outline

- **Objective**
  - Develop a high energy 2-micron pulsed coherent lidar system to demonstrate ground and airborne wind measurements. Develop conductively-cooled laser transmitter for space
- **Background and motivation**
- **Technology Development**
  - 1.2 Joule/pulse energy demonstration
  - Compact 2µm wind lidar transceiver
  - Conductive cooled 2µm oscillator/amplifier development
- **Ground and Airborne campaigns**

Motivation for 2µm Laser/Lidar Development
NRC Recommended "3-D Winds" Mission

"Knowledge derived from global tropospheric wind measurement is an important constituent of our overall understanding of climate behavior .[1]"

EARTH SCIENCE AND APPLICATIONS FROM SPACE

NATIONAL IMPERATIVES FOR THE NEXT DECADE AND BEYOND

Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future

Space Studies Board

Division on Engineering and Physical Sciences

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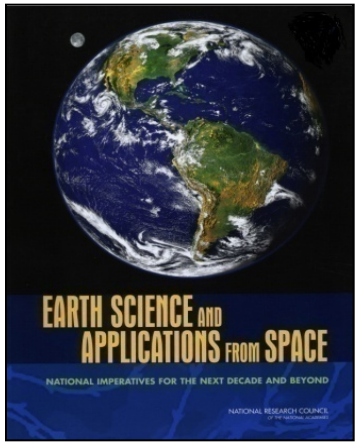


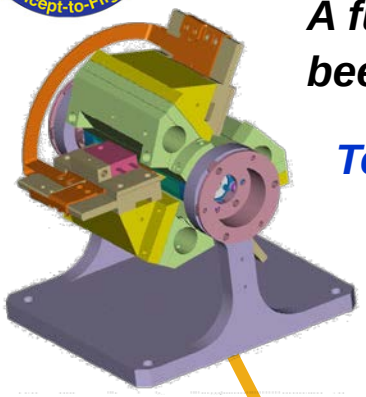
Global Winds 9 Societal Benefits	
Extreme Weather Warnings	✓
Human Health	✓
Earthquake Early Warning	
Improved Weather Prediction	**✓#1**
Sea-Level Rise	
Climate Prediction	
Freshwater Availability	
Ecosystem Services	
Air Quality	✓

[1] Baker et al., *Lidar measured Wind Profiles – The Missing Link in the Global Observing System*, Bulletin American Meteorological Society. 95 (4), 515-519 (April 2014)

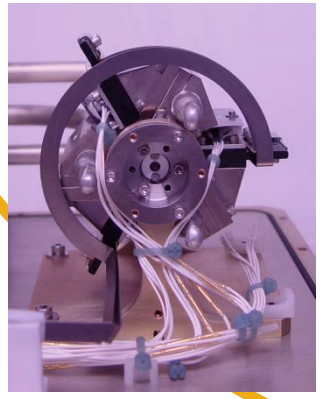
Wind Lidar Technology Maturation

A fully conductively cooled 2-micron solid-state pulsed laser has been demonstrated for the first time.

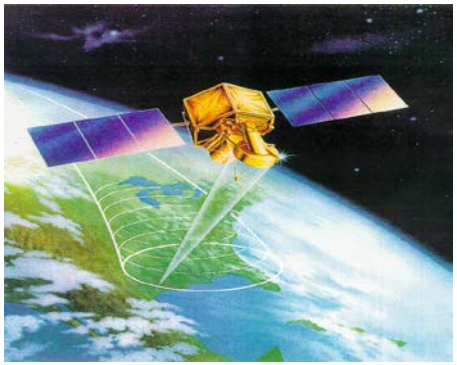
Technology Enables: Measurement of global 3-D Winds



Analysis & Design

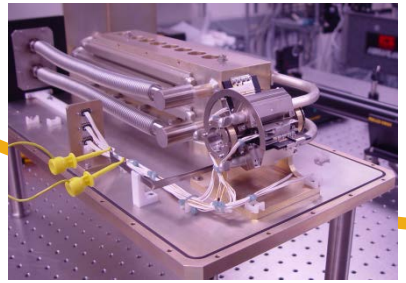


Fabrication



Space Qualifiable Design

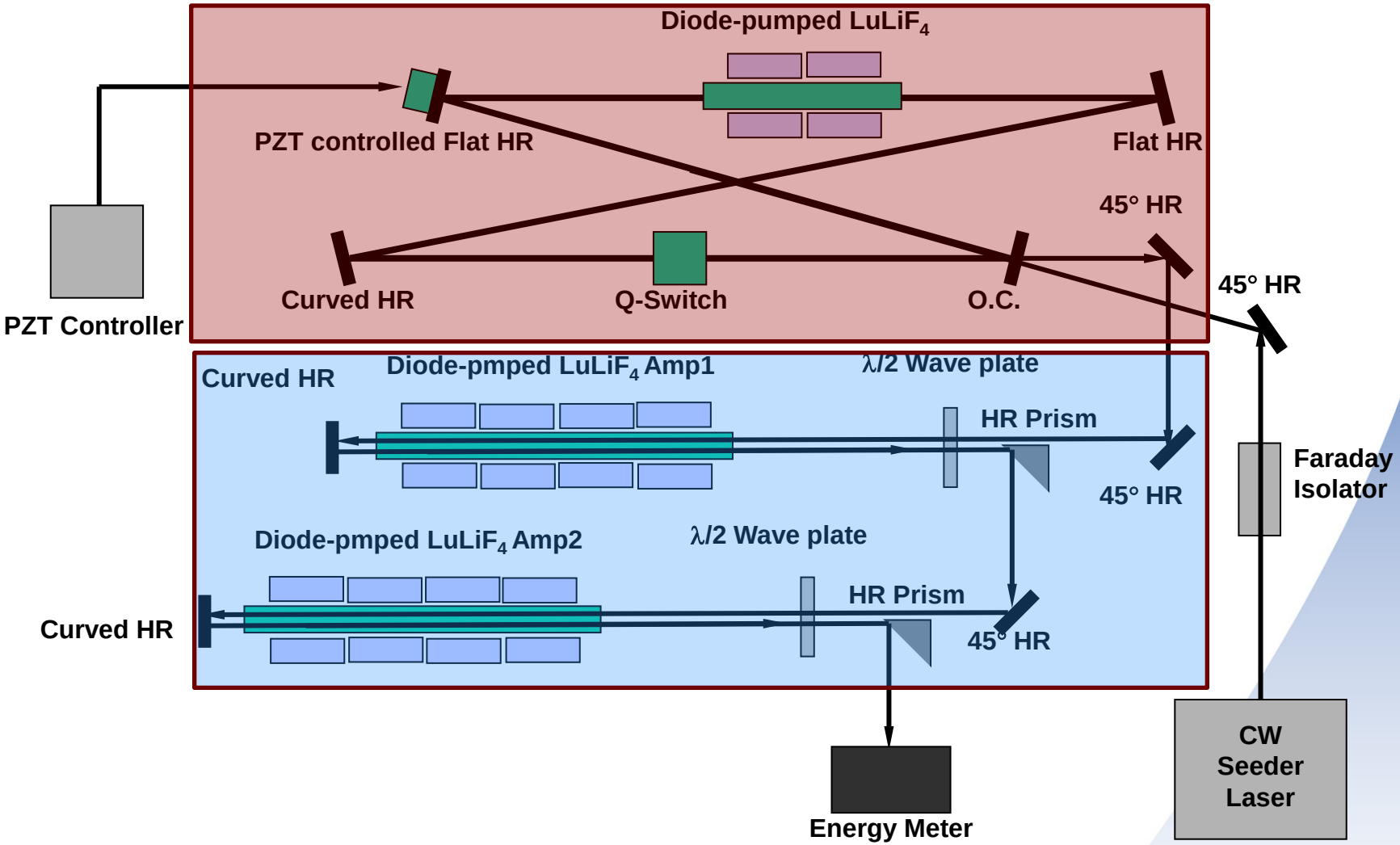
Quantum Mechanical Modeling



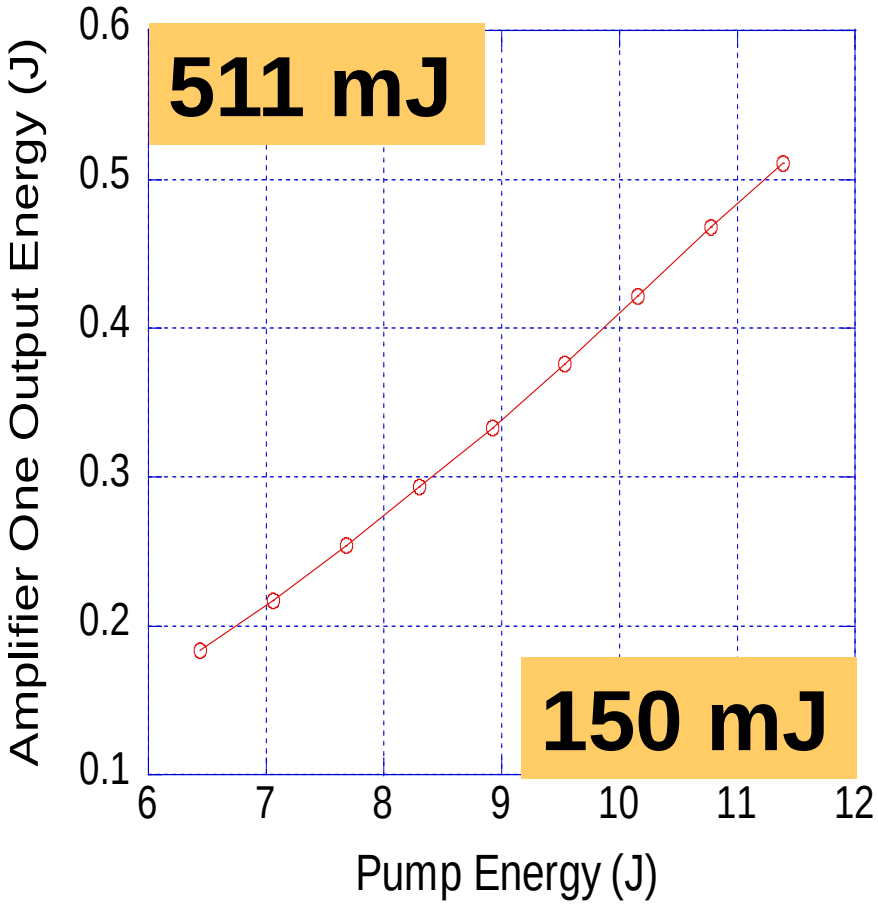
System Integration

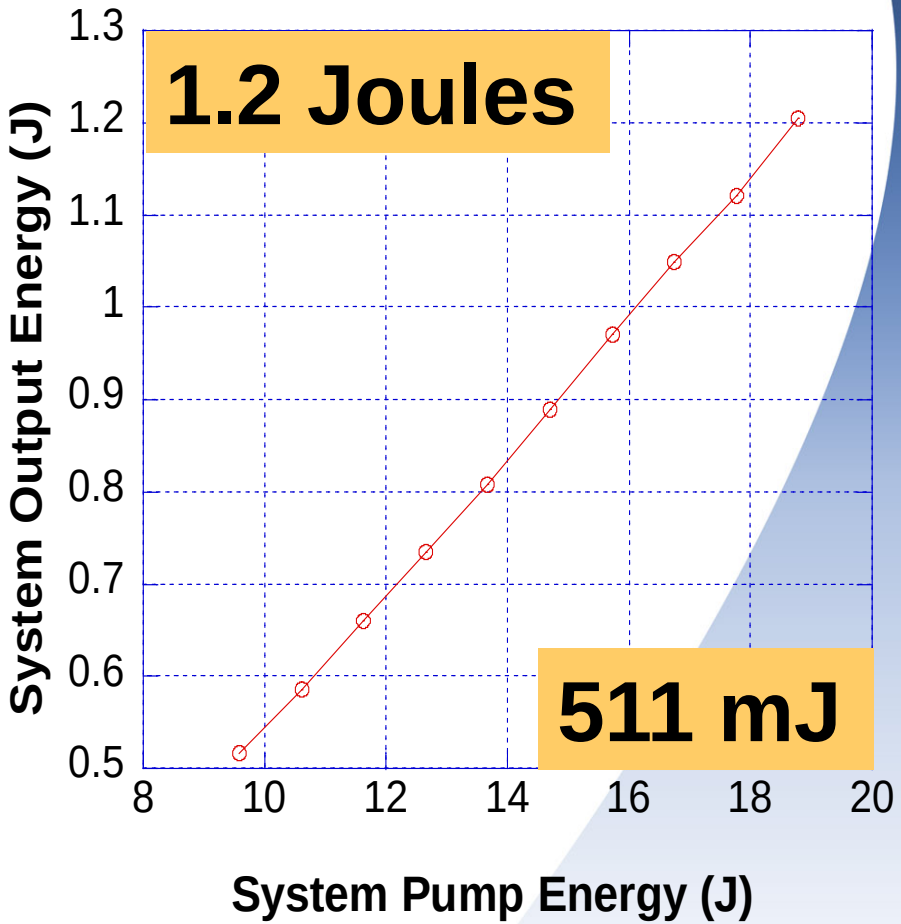
Testing and Model Verification

MOPA Schematic



Amplifier Performance





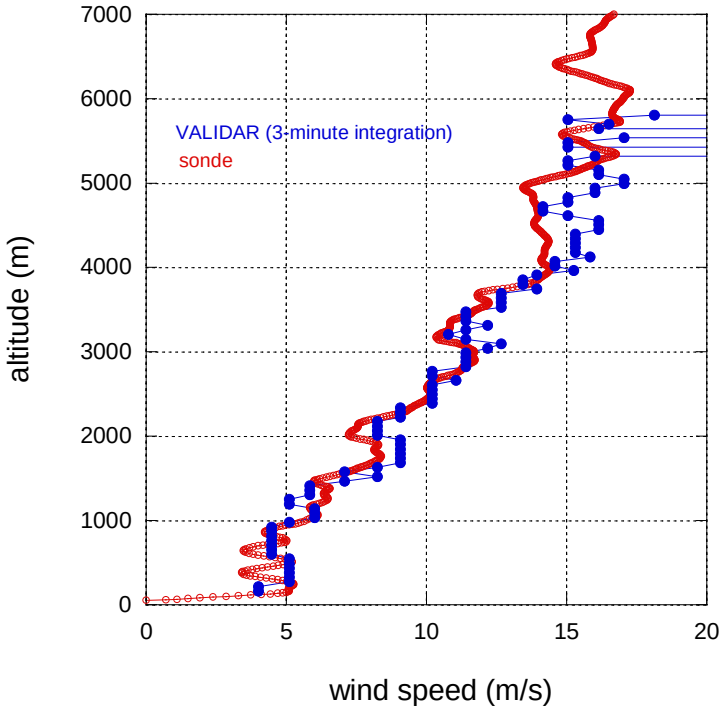
Basic Performance Goals for 2µm Doppler Lidar

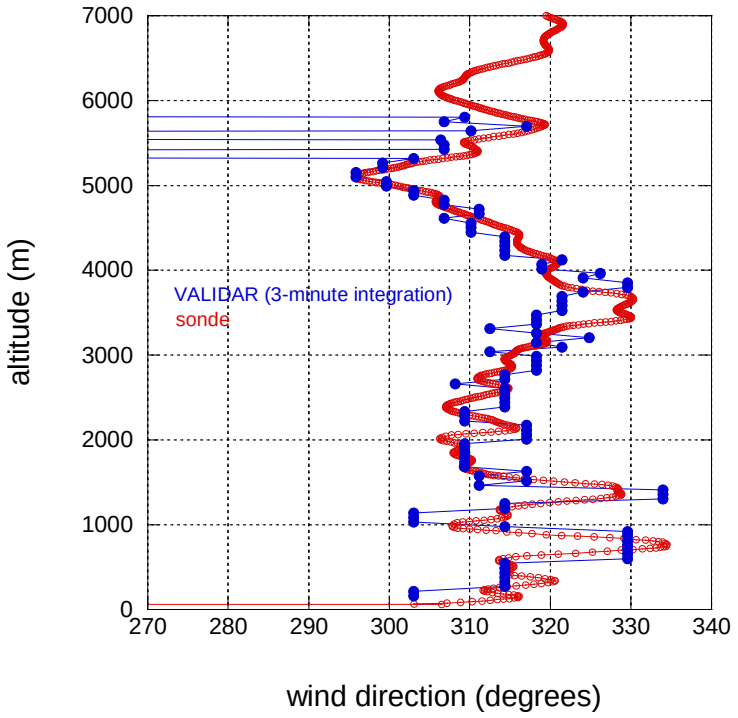
Wavelength	2.053 -µm
Laser Pulse Energy	250 mJ
Repetition Rate	10 Hz
Pulse Width	>150 ns
Beam Quality	$M^2 < 1.2$
Pulse Spectrum	Single frequency (seeded)
Cooling	Conductively cooled via heat pipes
Laser Size	23.9” x 14” x 7.7” (L x W x H) Including heat pipes and condenser

Ground-Based Hybrid Wind Lidar Demo

- The LaRC mobile lidar is deployed as part of NASA HQ funded Program
- Utilized NASA LaRC Compact DAWN Lidar Transceiver for 2-µm lidar
- Site at Howard University Research Campus in Beltsville, Maryland

Comparison of Coherent Lidar and Sonde

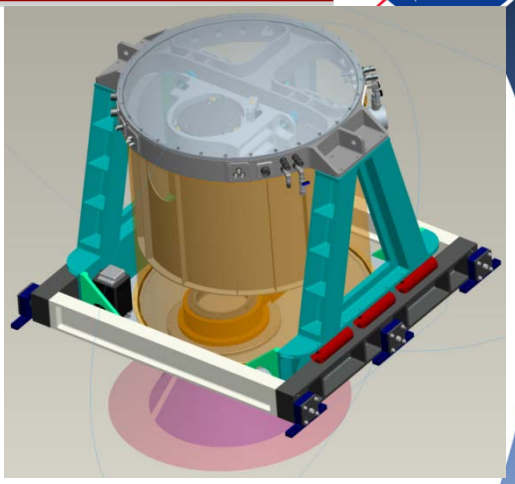


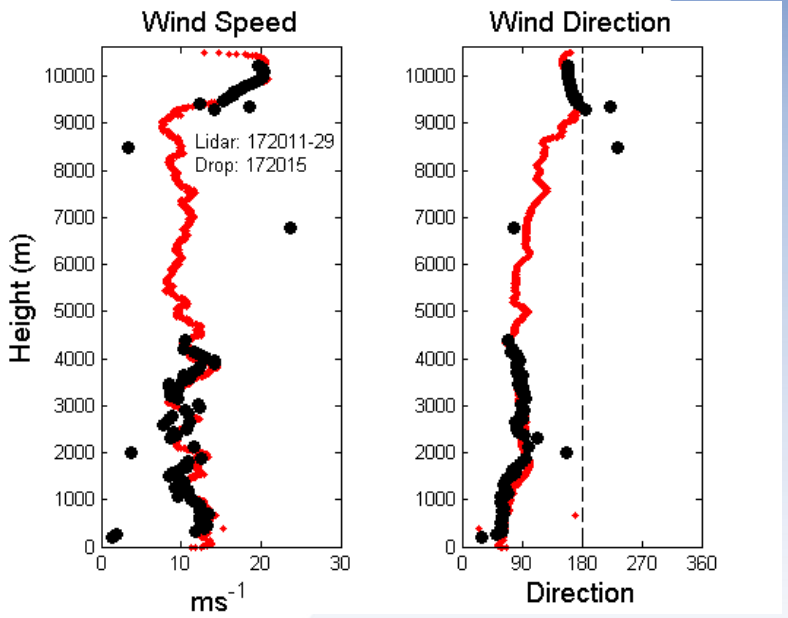


- Root-mean-square of difference between two sensors for all points shown is **1.06 m/s** for wind speed and **5.78 deg.** for wind direction

DC-8 Wind Lidar During GRIP (2010)

- Harden the transmitter for airborne application
- Add telescope and scanner within the enclosure
- Airborne wind measurement during GRIP campaign

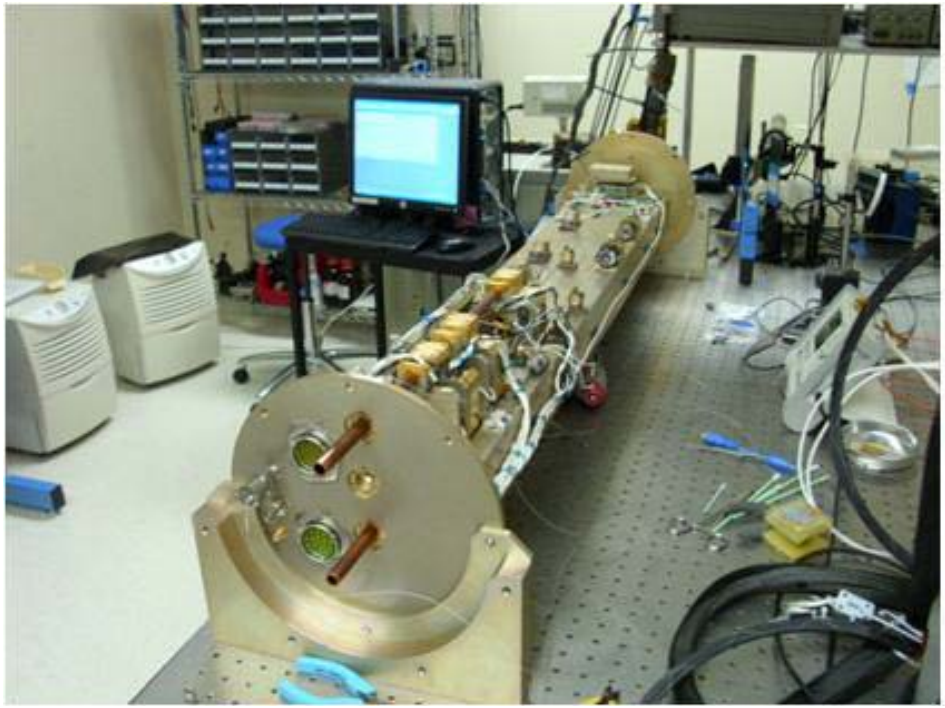


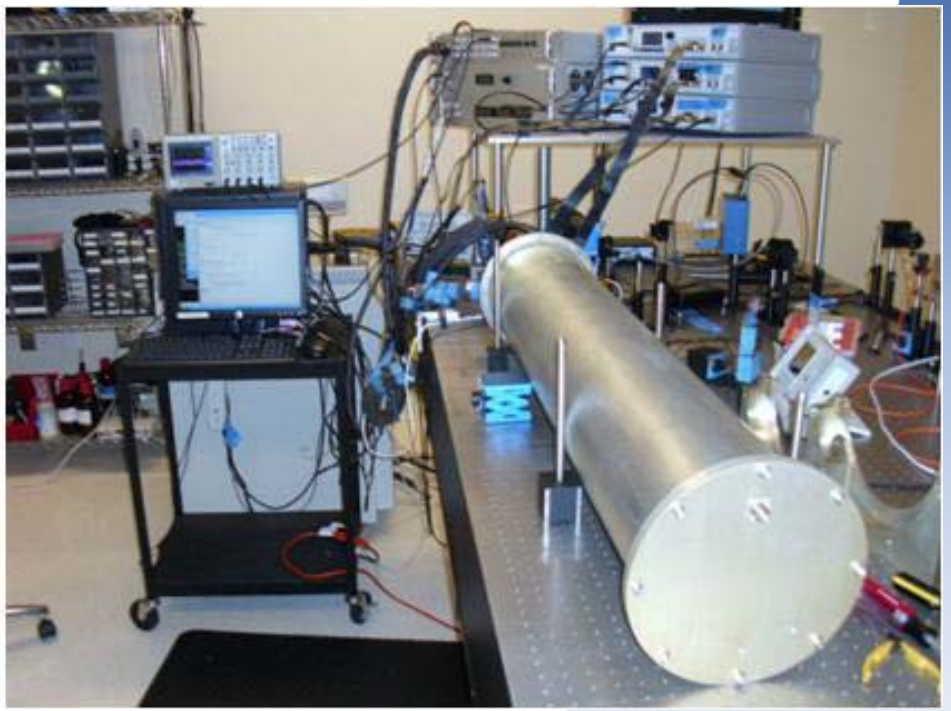


Innovative Partnership Program (LRRP/ESD/Fibertek) 2007-2010

(PI: Singh, Co-I: Yu, Kavaya LaRC; Co-I: Hovis, Fibertek)

Single frequency 2-micron Laser (200 mJ/5Hz) built and delivered by Fibertek to NASA LaRC





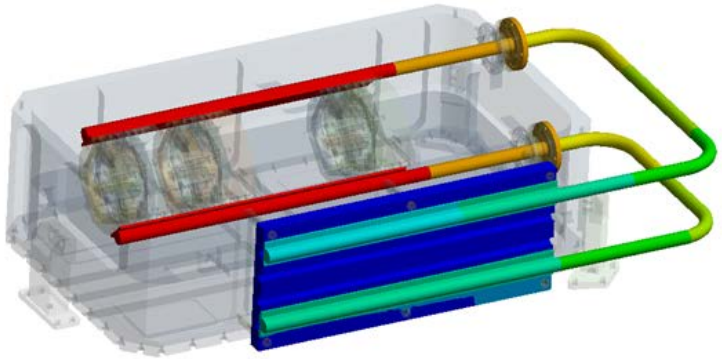
2-micron Risk Reduction Laser Transmitter

Design and Fabrication of a Breadboard, Fully Conductively Cooled, 2-Micron, Pulsed Laser for the 3-D Winds Decadal Survey Mission

PI: Upendra Singh, NASA LaRC

Objective

- Design and fabricate a space-qualifiable, fully conductively-cooled, 2-micron pulsed laser breadboard meeting the projected 3-D Winds mission requirements
    - Utilize improvements in key technologies including high-power, long-life space-proven 804 nm pump diodes; derated diode operation, and heat pipe conductive cooling
- Perform a long-duration life test on the laser system to evaluate mission readiness.



2-Micron Space Qualifiable Pulsed Laser for 3-D Winds

Approach:

- Leverage LaRC 2-micron laser development from earlier efforts
- Utilize Fibertek CALIPSO mission flight laser design and development knowledge
- Upgrade previous Fibertek two-micron laser design for flight-like laser based on space heritage
- Utilize space-ready, sealed cylindrical package
- Perform vacuum and lifetime tests while operating at the output requirements of the 3-D Winds mission

Co-Is/Partners: Jirong Yu, Mulugeta Petros, Michael Kavaya, LaRC; Floyd Hovis, Tim Shuman, Fibertek, Inc.

Key Milestones

• Complete laser mechanical design update and improved laser thermal modeling	01/13
• Assemble and test heat pipe cooled module	04/13
• Fabricate and test ring laser with heat pipe cooled module	12/13
• Install and test amplifiers	03/14
• Integrate with canister and test	04/14
• Vacuum-test laser	10/14
• Complete 8 months of life testing	03/15
• Complete analysis and performance testing	04/15

$TRL_{in} = 3$ $TRL_{current} = 3$

Outline

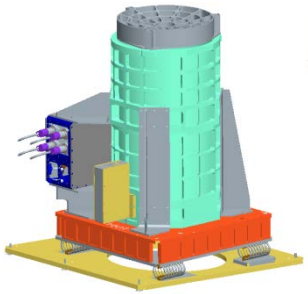
- Objective
  - Develop a high energy double-pulsed 2-micron direct detection IPDA lidar system to demonstrate airborne atmospheric CO_2 measurements
    - Spectroscopy and IPDA simulation
    - 2-micron double pulsed IPDA lidar
    - IPDA Ground Testing
    - IPDA lidar Airborne Demonstration
    - Summary and Conclusions

Development of a Double-Pulsed 2-micron Direct Detection IPDA Lidar for CO_2 Column Measurement from Airborne Platform

PI: Upendra N. Singh, NASA LaRC

Objective

- Develop, integrate and demonstrate a 2-micron pulsed Integrated Path Differential Absorption Lidar (IPDA) instrument CO_2 Column Measurement from Airborne platform
- Conduct ground validation test to demonstrate CO_2 retrieval
- Conduct engineering test flights to demonstrate CO_2 retrieval from UC-12 aircraft
- Conduct post flight data analysis for the purpose of evaluation of CO_2 measurement capability



Mobile and Airborne 2µm IPDA LIDAR system

Approach:

- Repurpose existing hardware including previously developed transmitter, receiver and data acquisition system
- Complete fabrication of transmitter, wavelength control and receiver units assembly
- Integrate existing and to be developed subsystems into a complete breadboard lidar system
- Fabricate a mechanical structure and integrate completed subsystem

Co-Is/Partners: Jirong Yu, Mulugeta Petros, Syed Ismail, NASA LaRC

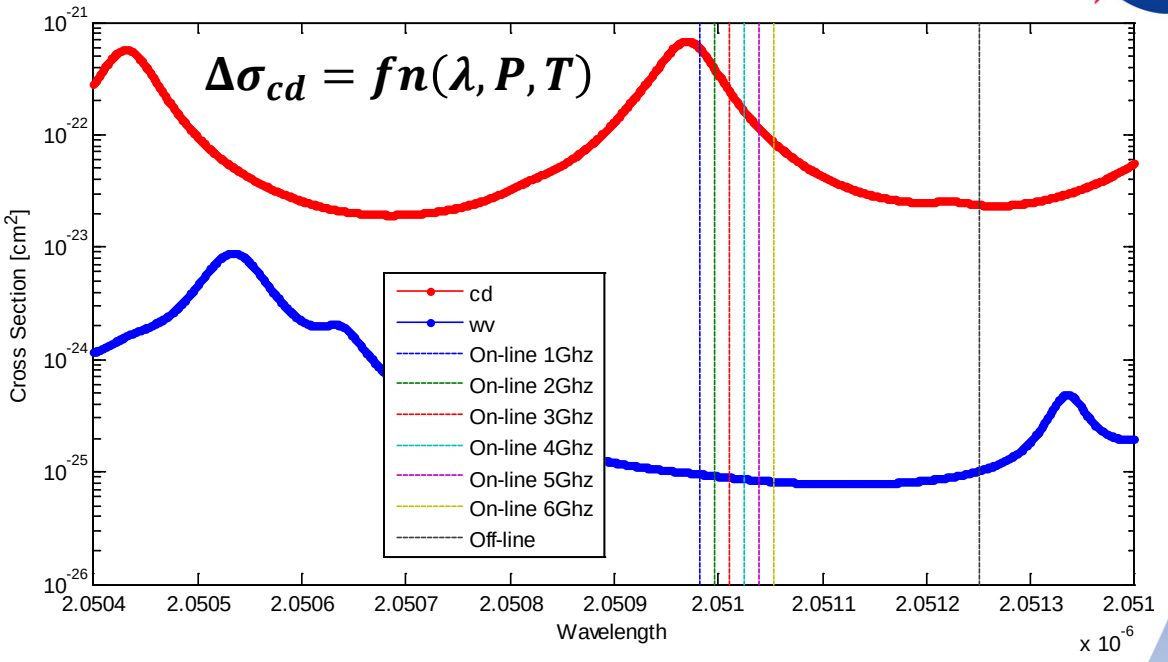
Key Milestones

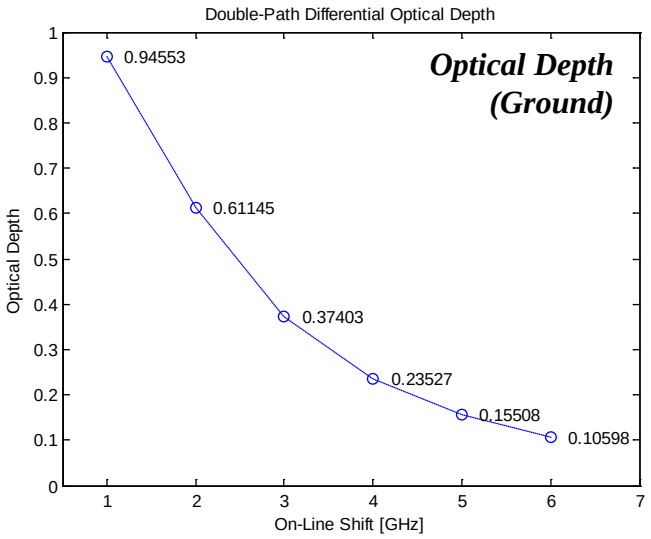
• Design of laser transmitter assembly	10/12
• Design, manufacture and assembly of receiver	04/13
• Integrate subsystems into breadboard lidar system	06/13
• Conduct ground test of the integrated lidar assembly	07/13
• Integrate lidar system on UC-12 aircraft	11/13
• Conduct post flight data analysis	09/14

$TRL_{in} = 3$ $TRL_{out} = 5$ (AIRCRAFT)

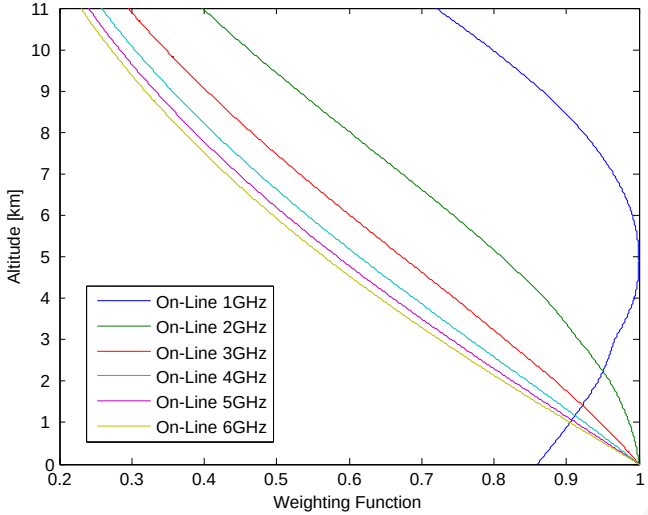
Spectroscopy

- Standard models are used for estimating optical depth, return pulse strength, SNR and errors for any operating condition.
- Modeling and meteoro-logical data are used for XCO2 derivation.



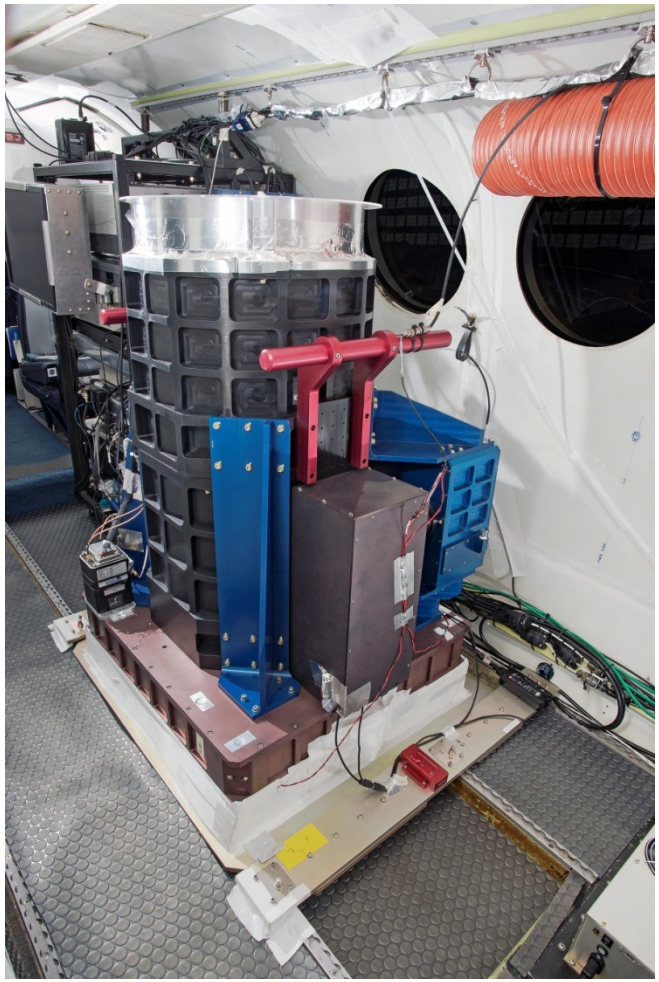


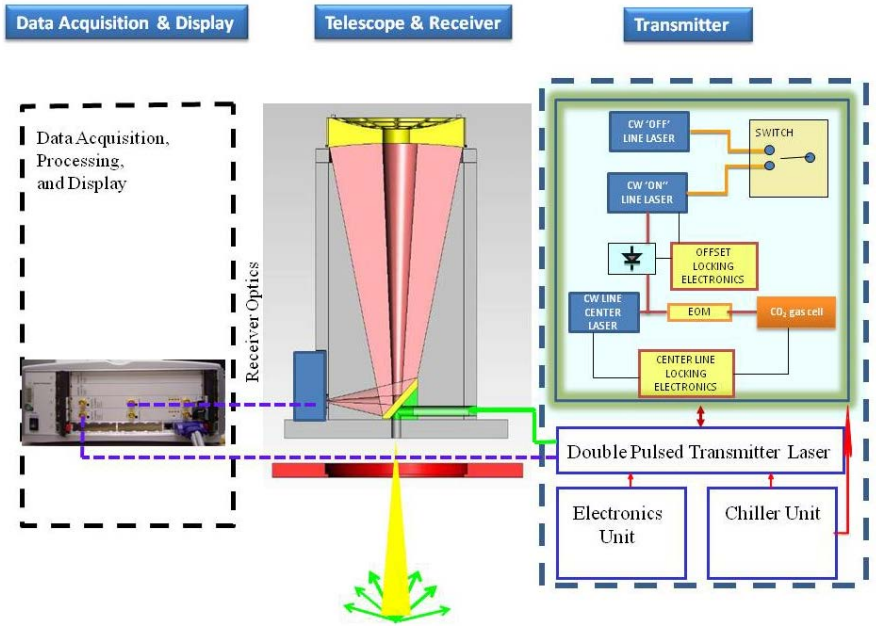
Optical Depth (Ground)



Pressure-Based Weighting-Functions (Airborne)

2-micron Double Pulsed IPDA Lidar





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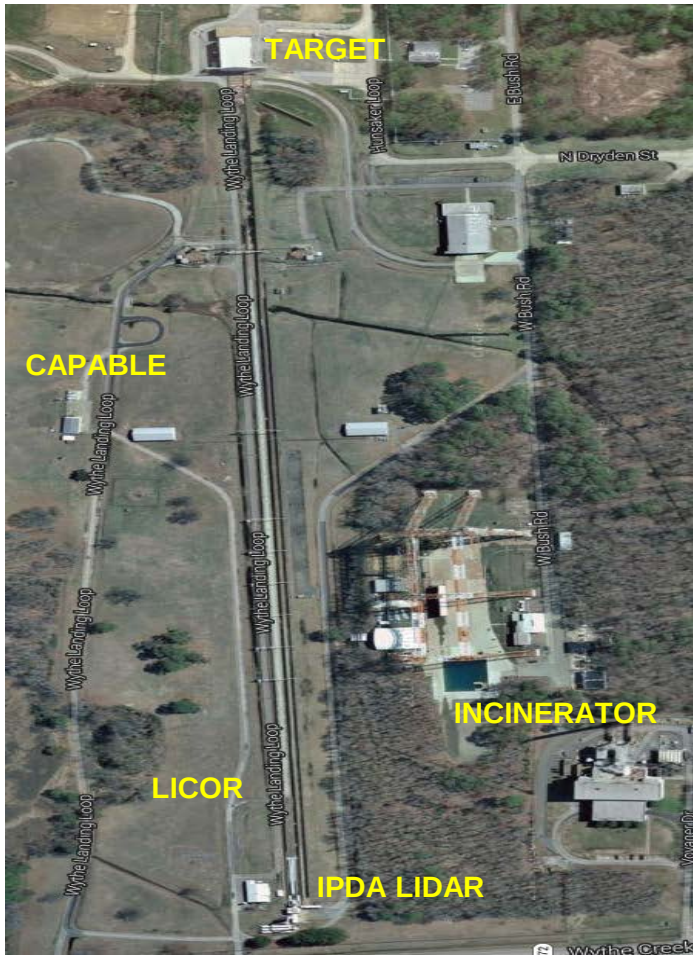
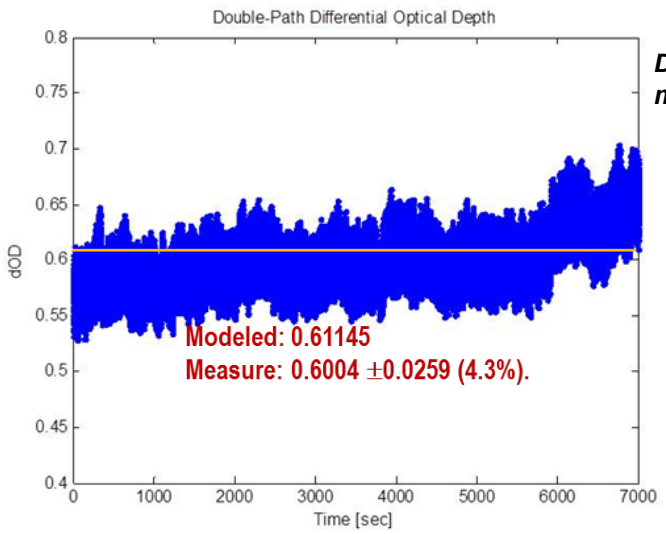
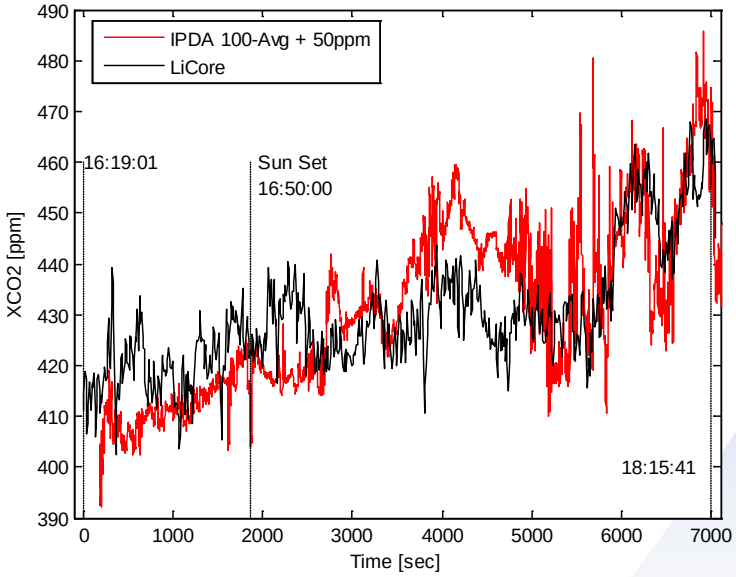
IPDA Ground Testing: Setup & Measurement





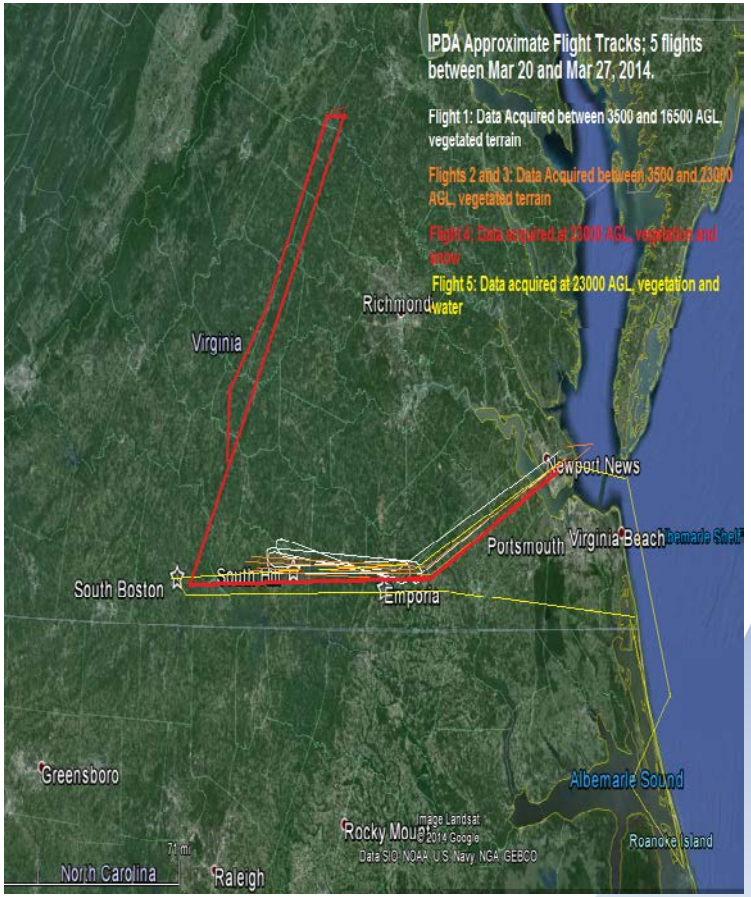
Differential optical depth– model and measurement



Dry mixing ratio IPDA vs (in-situ) measurement

10 Flights in March & April 2014

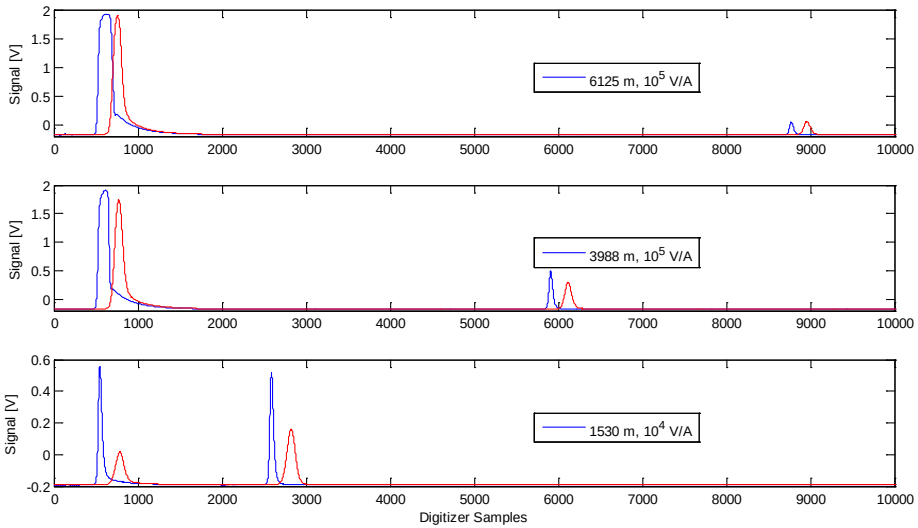
Date	Purpose	Duration	Location
March 20	Instrument Check Flight	2.1 hr	VA
March 21	Engineering	2.7 hr	VA
March 24	Engineering	3.0 hr	VA
March 27	Early morning	3.0 hr	VA
March 27	Mid-afternoon	2.5 hr	VA
March 31	Inland-Sea	2.5 hr	VA, NC
April 02	Power Station	2.4 hr	NC
April 05	With NOAA	3.7 hr	NJ
April 06	Power Station	3.0 hr	NC
April 10	Late afternoon	2.3 hr	VA

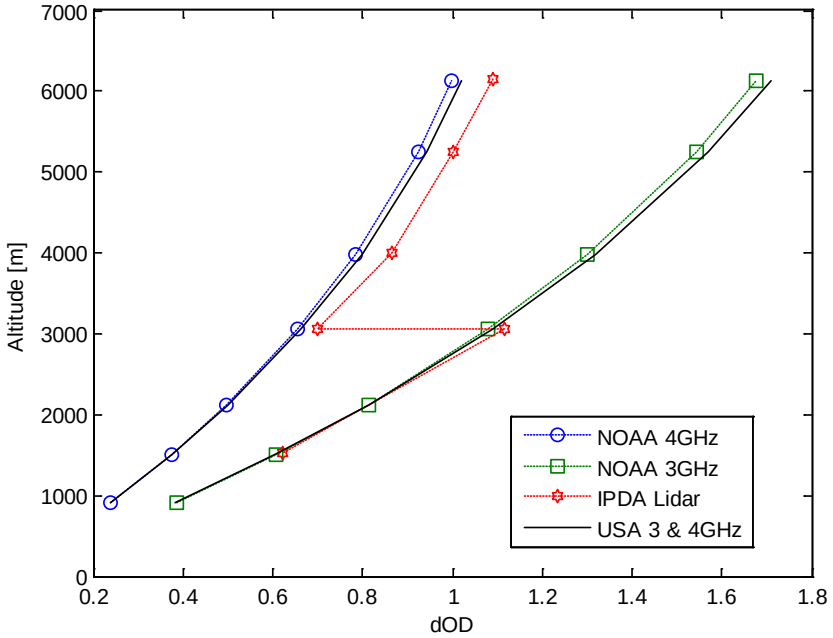


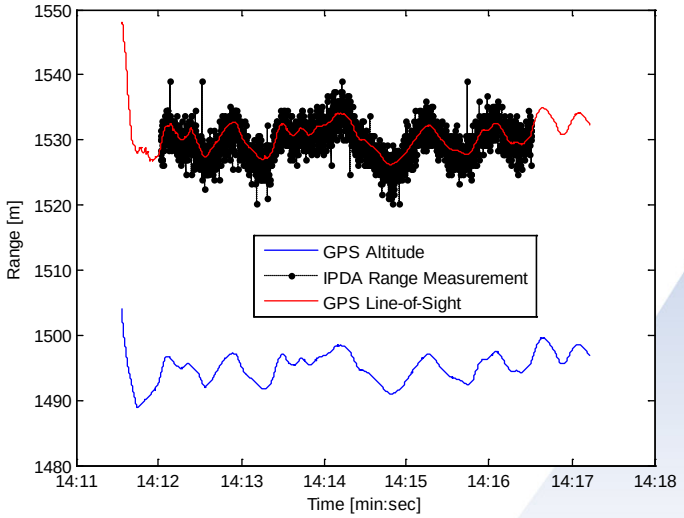
- Aircraft had temperature, pressure, humidity sensors, LiCor and GPS
- Some of the flights were supported by balloon launches

IPDA Airborne Testing: Sample Return Signals

- NOAA air sampling and IPDA lidar optical depth comparison.
- Return signal samples from different altitudes up to 6km.
- IPDA range measurements compared to on-board GPS.



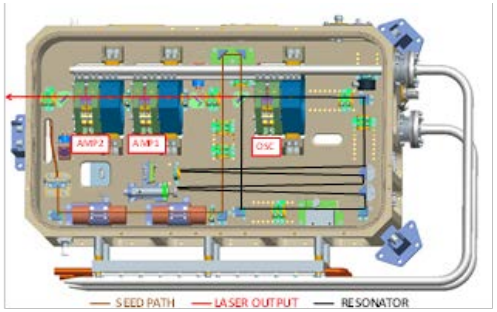




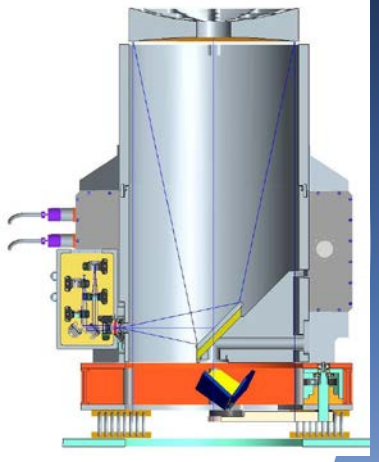
Triple-Pulsed 2-µm Direct Detection Airborne Lidar for Simultaneous and Independent CO_2 and H_2O Column Measurement – Novel Lidar Technologies and Techniques with Path to Space

PI: Upendra Singh, NASA LaRC

- Demonstrate and validate simultaneous and independent measurement of the weighted-average column dry-air mixing ratios of carbon dioxide (XCO_2) and water vapor (XH_2O) from an airborne platform
- Design and fabricate a space-qualifiable, fully conductively-cooled, triple-pulsed, 2-µm laser transmitter
- Design and develop wavelength control system for rapid and fine tuning of the three sensing lines of the CO_2/H_2O Integrated Path Differential Absorption (IPDA) lidar
- Integrate laser transmitter with receiver to develop the triple-pulsed 2-µm direct detection IPDA lidar
- Conduct extensive ground and airborne column CO_2/H_2O measurement and validate with *in-situ* sensors



An example of space-qualifiable, fully conductively-cooled 2-µm laser packaging from ACT 11



Integrated 2-µm CO_2/H_2O Airborne packaged IPDA Lidar

- Team with industry to utilize extensive space-flight laser development expertise to build a unique triple-pulsed 2-µm laser
- Develop a novel, lightweight, frequency agile, wavelength tuning and locking system for triple-pulsed IPDA Operation
- Integrate state-of-the-art laser transmitter to the existing and upgraded receiver system and strengthen for stable flight operation
- Conduct initial ground testing and validation of the IPDA lidar from a mobile lidar trailer
- Conduct extensive ground and airborne column CO_2/H_2O measurement and validate with in-situ sensors

Co-Is/Partners: Ken Davis, Penn State Univ; Jirong Yu, Mulugeta Petros, LaRC; Floyd Hovis, Fibertek, Inc.

- Complete the preliminary triple pulse laser optical, mechanical, thermal and structure design and analysis — 12/14
- Complete laser wavelength control unit design — 03/15
- Complete laser transmitter design, and mechanical lidar system design and breadboard testing — 09/15
- Complete fabrication and testing of laser transmitter and wavelength control unit — 07/16
- Integrate laser transmitter with wavelength control unit — 09/16
- Complete lidar integration, and ground test — 03/17
- Conclude CO_2/H_2O airborne lidar demonstration and final report — 06/17

$TRL_{in} = 3$ $TRL_{out} = 5$

Summary and Conclusions

- Development of Ho:Tm:LuLif and Ho:Tm:YLF lasers are enabling for Wind and CO_2 measurement
- NASA Langley Research Center has successfully developed Coherent Wind Lidar for ground and airborne measurement of Wind
- The intercomparison of ground and airborne measurements with balloon sonde shows excellent agreement in wind velocity and direction
- Technology advancement for a fully conductively-cooled 2-micron laser are on going
- A 2-micron double-pulsed, high energy IPDA lidar system has been developed
- Preliminary analysis of ground based hard target measurement demonstrates the 2-μm CO_2 IPDA lidar capability of measuring CO_2 optical depth and deriving XCO2.
- The IPDA instrument was operated on NASA B-200 aircraft through different conditions
- The measurement includes ranging capability with 1 m precision
- Observed single-shot signal-to-noise ratio from hard target larger than 200
- Future work towards developing a triple-pulsed IPDA lidar system is progressing

Thanks for your Attention